Preparation of Charge Strippers for the RIKEN RI-Beam Factory

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Abstract

In the RIKEN RI-Beam Factory (RIBF), ions from hydrogen to uranium are planned to be accelerated by four cyclotrons and linacs together with four stripper sections. The charge state fractions and required thicknesses of the charge strippers were estimated by measurements, a table, semi-empirical formulae, and calculation codes. The methods of estimating charge state fractions and stripper thicknesses to assemble charge stripping schemes of the RIBF are described. Selection of the charge strippers for the RIBF is described.

INTRODUCTION

Charge strippers are essential devices in a heavy-ion accelerator complex because the charge strippers increase the variety of acceleration schemes and decrease the construction costs of accelerators. However, charge strippers often limit the continuous operation of accelerators because the charge strippers are, on many occasions, the only device that breaks frequently, so it is important to decrease the frequency in the breakage of the charge strippers. It is also important to estimate charge state fractions accurately to assemble an acceleration scheme or design the accelerator itself.

The RIKEN RI-beam factory (RIBF) is an accelerator complex under construction. The first beam of the RIBF is scheduled to be accelerated in the end of 2006 [1]. Figure 1 shows a schematic view of the RIBF. The RIBF consists of four ring cyclotrons, the RIKEN ring cyclotron (RRC), the fixed-frequency ring cyclotron (fRC), the intermediate-stage ring cyclotron (IRC), and the superconducting ring cyclotron (SRC), another cyclotron for light ion and light heavy-ion injection, an AVF cyclotron, and linacs, the RIKEN heavy-ion linac (RILAC) and the charge-state multiplier (CSM), together with four stripper sections. The CSM makes possible a charge stripping at a higher energy than the injection energy of the RRC by a combination of an accelerator and a decelerator [2]. Four stripper sections are placed between the accelerator and decelerator of the CSM, the RRC and the fRC, the fRC and the IRC, and the RRC and the IRC, respectively. A typical objective of the beam is a 1 pμA uranium beam at 350 MeV/nucleon.

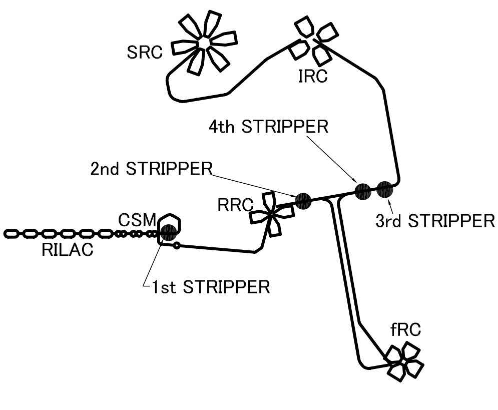

Figure 1: Schematic view of the RIBF.

Table 1 shows charge stripping schemes of typical ions, ^{238}U, ^{136}Xe, and ^{86}Kr in the RIBF. Uranium and xenon ions are planned to be accelerated by the RRC without being charge stripped by the first stripper after the acceleration by the RILAC. However, at the commissioning stage of the RIBF when a sufficient intensity of ^{238}U^{35+} beam is not supplied from the ion source, uranium beam of a low charge state is planned to be stripped to 36+ by the first stripper. In the xenon beam case, a sufficient intensity of ^{136}Xe^{20+} was already achieved by the ion source [3]. The uranium and xenon beams extracted from the RRC are charge stripped by the second stripper and injected into the fRC. Then, the beam extracted from the fRC is charge stripped again by the third stripper losing approximately 8% of its kinetic energy. The beam charge stripped by the third stripper is accelerated by the IRC and the SRC without further charge stripping. In the krypton beam case, it is estimated to be advantageous to accelerate without the fRC. In that case, the krypton beam is charge stripped by the first and fourth strippers.

ESTIMATION OF CHARGE STATE FRACTIONS

Most reliable method to estimate the charge state fractions is a measurement, of course, so the charge state fractions of, e.g., ^{136}Xe at 11 and 39 MeV/nucleon and ^{86}Kr at 2.7 and 46 MeV/nucleon were measured. However, it is difficult to measure the charge state fractions of every ion that is expected to be accelerated before the acceleration is actually realized, so other sources, e.g., a table [4], semi-empirical formulae (e.g. [5, 6, 7]), or calculation codes (e.g. [8, 9]) are employed. Figure 2 shows an example of the measurement on charge state fractions. The charge state fractions of ^{136}Xe were measured at 39 MeV/nucleon stripped by a carbon foil, an aramid film, or a polyimide film. The GLOBAL calculations [9] well

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Table 1: Parameters of the strippers for the RIBF.

	with the fRC					without the fRC	
Ion	^{238}U			^{136}Xe		^{86}Kr	
Stripper section	1st	2nd	3rd	2nd	3rd	1st	4th
Energy (MeV/nucleon)	0.9	11	51	11	51	2.7	46
Required charge-state	35+	72+	88+	42+	51+	26+	32+
Thickness (mg/cm^2)	0.025 [10]	0.5 [9]	14 [9]	0.15	20 [9]	0.04	0.3
Expecting charge-state	36+	72+	88+	44+	52+	26+	33+
Fraction	17% [4]	19% [9]	34% [9]	30%	44% [9]	31%	41%

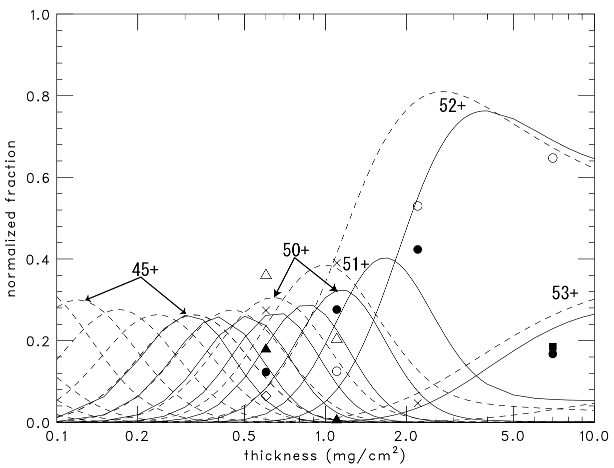

Figure 2: Charge state fractions of ^{136}Xe at 39 MeV/nucleon. Horizontal and vertical axes indicate the thickness of the strippers and the charge-state fractions, respectively. Blank diamonds, solid triangles, blank triangles, crosses, solid circles, blank circles, and a solid square indicate the measured charge state fractions from 47+ to 53+, respectively. The charge-state fractions are normalized by the area of the Gaussian fitted to the measured charge state distribution. Solid and dashed lines indicate the calculations by GLOBAL [9] and ETACHA [8], respectively.

reproduced the higher-charge state data. The charge state fractions of $^{136}Xe^{44+}$ at 11 MeV/nucleon, $^{86}Kr^{26+}$ at 2.7 MeV/nucleon, and $^{86}Kr^{33+}$ at 46 MeV/nucleon were measured to be 30%, 31%, and 41%, respectively. The charge state fraction of $^{238}U^{36+}$ was estimated by the table by Shima et al. [4]. The charge state fraction of $^{238}U^{72+}$ behind the second stripper was estimated by the experimental data by Scheidenberger et al. [9] because, fortunately, the extraction energy of the uranium beam from the RRC, 11 MeV/nucleon, is near the energy of the beam accelerated by GSI UNILAC. The charge state fraction of $^{238}U^{88+}$ behind the third stripper was estimated by the calculation code GLOBAL. The charge state fraction of ^{136}Xe behind the third stripper was also estimated by the GLOBAL calculation. The thicknesses of the strippers were selected by measurements changing the foil thickness, a semi-empirical formula [10], or the GLOBAL calculation.

CHARGE STRIPPERS

Four stripper sections are mainly characterized by the energy and intensity of the beams. The beam energy and intensity are, naturally, the lowest and the highest at the first stripper section and the highest and the lowest at the third or fourth stripper section, respectively.

First Stripper Section

When a 0.025 mg/cm^2 thick carbon foil is bombarded by a 90 pμA uranium beam at 0.9 MeV/nucleon, the lifetime of the foil is expected to be approximately 1 min [10, 11]. Therefore, the first stripper is planned to be applied to a uranium beam only at the commissioning stage of the RIBF, at which the beam intensity that bombards the first stripper is expected to be 1/100 of the target intensity. In the case of krypton beam, the condition is rather mild because the energy of the krypton beam that bombards the first stripper is higher than the uranium beam. A long-life carbon foil whose lifetime is more than 100 times longer than the foils on the market has been developed [12].

Second Stripper Section

A 15 pμA uranium beam at 11 MeV/nucleon is expected to bombard the second stripper, a 0.5 mg/cm^2 thick carbon foil. The beam is expected to deposit approximately 1 kW power to the stripper foil, which easily evaporates the foil. A rotating carbon foil stripper is under development now in order to cope with such a high energy deposit. The carbon foil that will be used in the rotating carbon foil stripper is also under development now.

Third Stripper Section

A uranium beam also deposits a high power on the third stripper. Because the thickness of the third stripper is large, 14 mg/cm^2, the uranium beam deposits approximately 8% of its kinetic energy. The power deposited by a 3 pμA uranium beam at 51 MeV/nucleon to a 14 mg/cm^2 thick carbon plate is approximately 3 kW. The power easily evaporates the carbon plate, so a rotating carbon disk stripper was constructed [13]. The maximum temperature of a 14 mg/cm^2 thick carbon disk rotating at 1000 rpm bombarded by a 3 pμA uranium beam was calculated using ANSYS to be 1549°C. A beam test was performed using a 0.1 pμA krypton beam at 46 MeV/nucleon, and no visible damage of the carbon disk was observed.

Fourth Stripper Section

The thickness range of the fourth stripper is approximately the same as the second stripper. On the other hand, the energy behind the stripper is the same as the third stripper, the injection energy of the IRC. Therefore, the condition is rather moderate compared with the other strippers, so it is planned to use an ordinary carbon foil stripper as the fourth stripper. Another possible solution to the fourth stripper is a liquid film stripper [14].

CONCLUSION

Four charge stripper sections are planned to be used in the RIKEN RI-beam factory. The charge state fractions and the thicknesses of the strippers were estimated by measurements, a table by Shima et al., a semi-empirical formula by Baron, and a calculation code GLOBAL. Charge strippers that are appropriate for the stripper sections, long-life carbon foils for the first stripper section, a rotating carbon foil stripper for the second stripper section, and a rotating carbon disk stripper for the third stripper section have been developed.

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